

DESCRIPTION

INFORMATION STORAGE APPARATUS

TECHNICAL FIELD

The present invention relates to a technique for an information storage apparatus that stores and reads information by irradiating a storage medium with an electron beam.

BACKGROUND ART

As an information storage apparatus that stores and reads information by irradiating a dielectric with an electron beam, an apparatus using a cathode ray tube (CRT) similar to that for display had been studied much before core memories and semiconductor memories were put into practical use (for example, U.S. Patent No. 2,755,994, column 2, lines 19 to 56.) In this patent, as in the case of displaying an image, a voltage of negative several thousand volts is applied to a red hot filament so as to emit thermoelectrons, and a dielectric (phosphor) is irradiated with an electron beam of the thermoelectrons, thereby storing and reading information.

More specifically, when a region of a dielectric associated with a storage bit is irradiated with a deflected electron beam, electron avalanche occurs in the irradiated region and electrons in the dielectric are emitted. In this state, the irradiated region becomes deficient in electrons. If the irradiation with the electron beam is stopped at this time, this electron deficiency state is maintained. On the other hand, if similar irradiation with an electron beam is performed from the region associated with the storage bit to its neighboring region according to scanning with the electron beam, electron avalanche also occurs in the neighboring region so that emitted electrons move to the region associated

with the storage bit. At this time, the electron deficiency in the region associated with the storage bit is eliminated and the region changes into an indeficiency state. Then, this indeficiency state is maintained. That is, data "0" or "1" is stored by maintaining the electron deficiency or indeficiency state as described above.

5 As described above, when the region in the electron indeficiency state is irradiated with an electron beam and thereby changes into a deficiency state, the potential at a pickup plate provided on a tube face of a CRT varies depending on the change of the state. On the other hand, even when the region already in the deficiency state is irradiated with an electron beam, such a potential variation does not occur. Accordingly, stored data is read
10 out by detecting a potential change (or current flowing due to the change) at the pickup plate.

—Problems to be solved—

However, conventional information storage apparatuses as described above utilizing irradiation with electron beams have been replaced with core memories and then
15 semiconductor memories, and are now not used at all because of the following reasons:

- (1) The sizes of apparatuses themselves are large;
- (2) Heaters and power supplies for the heaters are needed to emit thermoelectrons;
and
- (3) High voltages of about several thousand volts are required to emit electron
20 beams.

On the other hand, the semiconductor memories currently used in general have their sizes greatly reduced and storage densities greatly increased, as compared to the information storage apparatuses utilizing irradiation with electron beams. However, semiconductor processes have constraints in fabrication, and therefore there arises the
25 problem of difficulty in achieving a much higher density.

In view of this, it is therefore an object of the present invention to greatly increase the storage density so as to store a large amount of information.

DISCLOSURE OF INVENTION

5 To solve the foregoing problems, the present invention is characterized by including:

cold cathode electron beam emitting means; and

a storage medium for storing and reading information in accordance with irradiation with an electron beam emitted from the cold cathode electron beam emitting
10 means.

Storage and reading of information by irradiating the storage medium with an electron beam emitted from the cold cathode electron beam emitting means in the manner described above enables a minute region of the storage medium to store one bit of information. Accordingly, the storage density is greatly increased to allow storage of a
15 large amount of information. In addition, the size of the apparatus and power consumption are reduced and high-speed access is achieved.

As the cold cathode electron beam emitting means, a spindt-type cold cathode with a sharp point or a cold cathode in which one or a plurality of carbon nanotubes are placed on a base may be used, for example. Alternatively, a ballistic electron emitting element
20 may be used. Use of such cold cathode electron beam emitting means enables storage of a large amount of information easily with the area of a storage region for one bit reduced.

A cold cathode may be placed in a chamber surrounded by a partition and a film capable of transmitting an electron beam such that the inside of the chamber has a higher degree of vacuum than the outside thereof. In such a case, the degree of vacuum around
25 the carbon nanotubes, for example, is maintained and attachment of foreign matters and

others are prevented with ease. Accordingly, even in the case of a small number of carbon nanotubes, the beam spot size is more easily reduced so that the storage density is increased without decrease in stability of electron emission.

Furthermore, accelerating means for accelerating an electron beam emitted from
5 the cold cathode electron beam emitting means, deflection means for deflecting the electron beam in one- or two-dimensional directions, and convergence means for causing the electron beam to converge may be provided with a given electric field or magnetic field generated. Each of these means may not only be an individual component but also have two or more functions by setting an electrode form or an applied voltage. An electron
10 beam may be accelerated in such a manner that a plurality of electrodes to which voltages with different phases are applied are provided and thereby a moving electric field is generated. The cold cathode electron beam emitting means may be configured in such a manner that a plurality of electron emitting parts are provided to emit electron beams at different timings according to the distance from a given center so that the emitted electron
15 beams converge. With these configurations, the presence and absence of emission of an electron beam, the energy thereof and an irradiated position and an irradiated area on the storage medium, for example, are easily controlled.

To irradiate only a given region of the storage medium with an electron beam, the apparatus may be configured such that an electron beam passing through a minute hole
20 formed in shielding means such as a plate member reaches the storage medium. If at least one of such a plate member and the storage medium is moved by an actuator using a so-called micromachine technology, reduction of an area of the storage medium irradiated with an electron beam and control of the irradiated position are also easily achieved.

Examples of the storage medium for storing information by irradiation with an
25 electron beam as described above include: a phase change film that changes into a

crystallized state or an amorphous state in accordance with the energy of the electron beam for irradiation; a component using a material in which a hole is formed or whose film thickness varies by irradiation with an electron beam at a given energy level; an insulator film capable of accumulating and emitting charge in accordance with irradiation with an electron beam; and a component using a material which obtains a fluorescent property upon irradiation with an electron beam.

A plurality of electron beams may be emitted to strike a plurality of regions of the storage medium so that a plurality of bits of information is stored or read out at the same time. Accordingly, storage and reading are performed at higher speed.

10 Irradiated-position-shift detecting means for detecting a shift between a given reference position and a position in the storage medium irradiated with an electron beam may be provided so that the irradiated position is controlled by calibration or feedback control. Then, the accuracy in locating the irradiated position is enhanced, and the storage density is more easily increased.

15 Part of information stored and read out at the same time may be used for error detection or error correction.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a diagram illustrating a configuration of an information storage apparatus including one information storage cell.

FIG. 2 is a perspective view illustrating an example of an accelerating electrode 102.

FIG. 3 is a side view illustrating an example of a cold cathode 101.

FIG. 4 is a side view illustrating another example of the cold cathode 101.

25 FIG. 5 is a side view illustrating yet another example of the cold cathode 101.

FIG. 6 is a side view illustrating still another example of the cold cathode 101.

FIG. 7 is a side view illustrating still another example of the cold cathode 101.

FIG. 8 is a cross-sectional view illustrating still another example of the cold cathode 101.

5 FIG. 9 is a cross-sectional view illustrating an example of a ballistic electron emitting element.

FIG. 10 is an illustration showing an example in which a component serving as both the accelerating electrode 102 and a convergence electrode 103 is used.

10 FIG. 11 is an illustration showing an example in which a component serving as both the accelerating electrode 102 and a deflection electrode 104 is used.

FIG. 12 is a front view illustrating an example of an electrode serving as both of the accelerating electrode 102 and the deflection electrode 104.

FIG. 13 is an illustration showing an example of annular electrodes 302 for generating a moving electric field.

15 FIG. 14 is a side view illustrating an example of the cold cathode 101 for emitting an electron beam which will converge.

FIG. 15 is an illustration showing another configuration for controlling a region irradiated with an electron beam.

20 FIG. 16 is an illustration showing yet another configuration for controlling a region irradiated with an electron beam.

FIG. 17 is a perspective view showing a configuration of an information storage apparatus including a plurality of information storage cells.

25 FIG. 18 is a block diagram showing a connection relationship among cathode ray drivers and other elements in the information storage apparatus including the plurality of information storage cells.

FIG. 19 is an illustration showing a configuration of a servo cell for controlling a position irradiated with an electron beam.

FIG. 20 is an illustration showing an example in which some of the information storage cells are used for error correction.

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BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, embodiments of the present invention will be described with reference to the drawings.

(Information storage apparatus including one information storage cell)

10 FIG. 1 is a view schematically showing a configuration of an information storage apparatus including one information storage cell **100**.

A cold cathode **101** emits an electron beam E upon application of a negative voltage from a cathode ray driver **111**. The configuration of this cold cathode **101** will be specifically described later. The voltage applied to the cold cathode **101** may be a DC
15 voltage or a pulse driving voltage such as surge pulses.

An accelerating electrode **102** is made of an annular electrode as shown in FIG. 2, for example, and receives, from an acceleration controlling circuit **112**, a voltage higher than that applied to the cold cathode **101**. The accelerating electrode **102** extracts electrons from the cold cathode **101** by utilizing an electric field generated between the accelerating
20 electrode **102** and the cold cathode **101** and accelerates the electrons.

As the accelerating electrode **102**, a convergence electrode **103** is made of an annular electrode. Upon application of a given voltage from a convergence controlling circuit **113**, the convergence electrode **103** generates an electric field serving as a lens with respect to the electron beam E, and causes the electron beam E emitted and diverging from
25 the cold cathode **101** to converge.

The deflection electrode **104** includes a pair of opposed electrode plates **104a** and **104b** and deflects the electron beam **E** for scanning upon application of different voltages to the respective electrode plates **104a** and **104b** from a deflection controlling circuit **114**. In this case, a potential difference generator **114a** shown in FIG. 1 controls the potential difference between the electrode plates **104a** and **104b**. In the case of deflecting the electron beam **E** in two-dimensional directions, two pairs of deflection electrodes **104** may be provided.

A storage film **105** includes: a phase change film **105a** changing into an amorphous state or a crystallized state according to the degree of heating and cooling; a detection electrode **105b** provided on the side of the phase change film **105a** toward the cold cathode **101**; and an anode **105c** provided on the opposite side of the phase change film **105a**. The anode **105c** is grounded and the detection electrode **105b** is connected to a signal regenerator **115** to detect the potential difference between the detection electrode **105b** and the anode **105c**. The size and pitch of a storage region for one bit in the storage film **105** is determined in accordance with permissible accuracies (variations) in the amount of deflection and the degree of convergence of an electron beam.

The cathode ray driver **111**, the acceleration controlling circuit **112**, the convergence controlling circuit **113** and the deflection controlling circuit **114** are configured by using D/A converters, for example. On the other hand, the signal regenerator **115** is configured by using an A/D converter.

In the information storage apparatus thus configured, information is stored and read out in the following manner.

When a potential difference at a given level or higher is applied across the cold cathode **101**, and the accelerating electrode **102**, electrons are emitted from the cold cathode **101**, accelerated by the accelerating electrode **102**, caused to converge by the

convergence electrode 103, and then deflected by the deflection electrode 104, thereby irradiating a minute region of the storage film 105 with an electron beam E. At this time, if the detection electrode 105b has a resistance higher than that of the phase change film 105a, current flows into the anode 105c and hardly diffuses through the detection electrode 105b and the phase change film 105a.

In this case, when a voltage applied to the cold cathode 101 or the accelerating electrode 102 is controlled such that the potential difference therebetween is higher than or equal to a given level to supply high energy to the electron beam E, the phase change film 105a is rapidly heated. Then, when the electron beam E is shut off by setting the potential difference between the cold cathode 101 and the accelerating electrode 102 at zero, for example, after a lapse of time enough to heat the phase change film 105a to a given temperature, the electron-beam irradiated region of the storage film 105 is rapidly cooled, so that the phase change film 105a changes into an amorphous state. On the other hand, when the potential difference between the cold cathode 101 and the accelerating electrode 102 is set at a level lower than the above level to reduce the energy of the electron beam E, the phase change film 105a is heated to a temperature lower than that in the case of high energy. When the electron beam E is shut off, this heated phase change film 105a is gradually cooled to be crystallized. By changing the phase change film 105a into the amorphous state and the crystallized state with different energies of the electron beam E as above mentioned, data "0" or data "1" is stored. In the case of crystallization, the energy of the electron beam E may be gradually lowered, for example.

The phase change film 105a has different resistance values between the amorphous state and the crystallized state. Accordingly, the potential difference between the detection electrode 105b and the anode 105c upon irradiation with an electron beam E at a low energy level at which the state of the phase change film 105a does not change is larger in

the case of the amorphous state than in the case of the crystallized state. In view of this, the potential difference is detected by the signal regenerator **115**, thereby reading stored information.

The position in the phase change film **105a** irradiated with the electron beam **E** is controlled at high speed by a voltage applied to the deflection electrode **104**. That is, no mechanical elements such as a hard disk and an optical disk are not included, so that it is possible to store and read information at an extremely high speed. A sawtooth wave may be applied to the deflection electrode **104** so as to scan the storage film **105** with an electron beam **E**. If a voltage which changes stepwise is applied, random access is obtained, so that access is performed at a higher speed.

(Specific configuration of cold cathode **101**)

Examples of the cold cathode **101** include: a spindt-type cathode having a sharp point and made of, for example, tungsten, silicon or diamond; a cathode using a carbon nanotube; and a cathode using a ballistic electron emitting element. In particular, in the cases of using the cathode using a carbon nanotube and the cathode using a ballistic electron emission element, an electron beam **E** is easily generated even with a potential difference between the cold cathode **101** and the accelerating electrode **102** of 10V or less. Accordingly, power consumption is greatly reduced and, in addition, a large amount of miniaturization of the entire structure is more easily achieved.

More specifically, as shown in FIG. 3, the cold cathode **101** using a carbon nanotube is configured in such a manner that one carbon nanotube **101b** is provided to stand on a base **101a** made of, for example, conductive silicon. If the carbon nanotube **101b** is provided in this way, the electron emission source is a point electron source, so that the spot size in a region of the storage film **105** irradiated with an electron beam is reduced to a diameter of about several nanometers. Accordingly, suppose a recording

point associated with one bit has a diameter of about 8 nm, if 128×128 recording points are arranged on a 1 μm -square recording face, 16 Kbits of information is stored.

Alternatively, the cold cathode **101** may include a plurality of carbon nanotubes. For example, as shown in FIG. 4, carbon nanotubes **101b** extending in random directions may be provided on the base **101a**. The cold cathode **101** having such a configuration is easily formed at a low cost by, for example, applying a solution in which carbon nanotubes are dispersed. In addition, such a cathode includes a large number of electron emitting edges, so that electrons are easily emitted with stability even at a relatively low degree of vacuum. In order to reduce the beam spot size in the presence of the carbon nanotubes **101b** on a relatively large area of the base **101a**, the convergence electrode **103** and other components only need to be set at high accuracy as in a converging optical system or the like. Alternatively, as shown in FIGS. 5 and 6, several carbon nanotubes **101b** may be provided by vapor deposition or other processes to locally stand on a region with a diameter of 100 nm or less. In these cases, electron emission more stable than in the case of providing one carbon nanotube **101b** is easily performed. In addition, the beam spot size is relatively easily reduced by making an electron emission source closer to a point electron source. Furthermore, as shown in FIG. 7, a large number of carbon nanotubes **101b** having substantially the same length may be densely arranged in substantially the same direction. In this case, more stable emission of electrons is easily performed and fabrication is relatively easily performed.

Moreover, as shown in FIG. 8, for example, the cold cathode **101** may be placed in a chamber surrounded by a partition **201** and a film **202** of a thin film made of, for example, gold with a high ductility and capable of transmitting an electron beam such that the inside of the chamber has a higher degree of vacuum than the outside thereof. Specifically, it is not always easy to maintain a high degree of vacuum between the cold

cathode **101** and the storage film **105** because molecules are readily scattered during collision of electrons with the storage film **105**. However, if the cold cathode **101** is placed in the small chamber as described above, the space surrounding the cold cathode **101** is kept at a high degree of vacuum and adhesion of foreign matters to the cold cathode **101** is prevented, so that stable emission of electrons is performed even in the case of providing a small number of carbon nanotubes. Accordingly, the beam spot size is more easily reduced without decrease in stability of electron emission. In the foregoing configuration, a conductive film may be used as the film **202** to also serve as the accelerating electrode **102**.

In addition, a ballistic electron emitting element that may replace the cold cathode **101** as described above is obtained by, for example, forming silicon impalpable particles **204** in a minute cavity **203** with a diameter of about 100 nm or less as shown in FIG. 9. In the case of using such a ballistic electron emitting element, stable emission of a high-energy electron beam is easily achieved.

(Configuration of accelerating electrode **102** and other components)

The accelerating electrode **102**, the convergence electrode **103** and the deflection electrode **104** are not limited to the above-described electrodes including the annular electrodes and opposed electrodes and may be cylindrical electrodes, coils for generating magnetic fluxes, or any combination of such electrodes and coils. In addition, a plurality of convergence electrodes **103** may be provided to generate a desired electric field with higher accuracy.

In addition, as shown in FIG. 10, for example, only one of the accelerating electrode **102** and the convergence electrode **103** may be provided and have functions of accelerating the electron beam **E** and causing the electron beam **E** to converge upon application of a positive voltage to the cold cathode **101**.

Furthermore, as shown in FIGS. 11 and 12, an annular electrode 301 may be divided into four so as to replace both of the accelerating electrode 102 and the deflection electrode 104. In addition, if the average potential of the divided electrodes 301a through 301d is higher than that of the cold cathode 101 and the divided electrodes 301a and 301b and/or the divided electrodes 301c and 301d have a potential difference/potential differences, i.e., if the relative potentials of the respective divided electrodes 301a through 301d are controlled, the electron beam E is accelerated and deflected. (In the case of deflecting the electron beam E only in one-dimensional directions, for example, the annular electrode 301 only needs to be divided into two.)

Alternatively, a component serving as both the convergence electrode 103 and the deflection electrode 104 may be used. (In this case, it can be considered that adjustment of relative potentials moves the center of an equivalent electron lens so that the focal point of an electron beam shifts in the X-Y direction.) Furthermore, a component serving as the accelerating electrode 102, the convergence electrode 103 and the deflection electrode 104 may be used with a positive voltage applied to the divided electrodes 301a through 301d as described above. That is, the components such as the accelerating electrode 102 do not necessarily need to be physically separated and it is sufficient for these components to have the above functions as a whole.

If an electron beam E with sufficient energy is obtained by using the potential difference between the cold cathode 101 and the storage film 105, it is unnecessary to provide the accelerating electrode 102.

As shown in FIG. 13, for example, a plurality of annular electrodes 302 may be provided such that pulse voltages with different phases are sequentially applied to generate a moving electric field and thereby accelerate the electron beam E. In this case, the generated electrode beam E has high coherence with, i.e., the same speed and same phase

as, the moving electric field. Accordingly, the beam spot size is more easily reduced.

Furthermore, as shown in FIG. 14, for example, carbon nanotubes **101b** densely arranged to form a plane may be divided into a plurality of regions, e.g., concentric regions, and electron-beam generating pulse voltages with different delay times may be applied to the respective regions of the carbon nanotubes **101b**. Then, the electron beam E converges according to a principle similar to that in a phased array radar.

(Other configurations for controlling region irradiated with electron beam E)

Instead of convergence and deflection of an electron beam E as described above, at least one of a shielding plate **401** in the shape of a plate having a minute hole **401a** (pin hole) and the storage film **105** may be moved by an actuator **402**, as shown in FIG. 15, for example. The actuator **402** may be constructed by an electrostatic actuator unit and an elastic member, for example. If two pairs of electrostatic actuator units and others are used, a two-dimensional drive is easily performed.

By shielding an electron beam E by using the shielding plate **401** as described above, control of a region irradiated with the electron beam E is ensured and the storage density is easily increased. In addition, an electron emitting part of the cold cathode **101** does not need to be very small, so that stable emission of electrons is easily achieved. In addition, the configuration is simplified because the convergence electrode **103** and other components are not needed. However, the convergence electrode **103** and other components may be provided to enhance the energy of the electron beam and to perform convergence and deflection of the electron beam so that the efficiency in utilizing the electron beam is increased. Even in such a case, the region irradiated with the electron beam is accurately controlled by the shielding plate **401**, so that the accuracy in controlling convergence and deflection does not need to be maintained at such a high level.

In a case where the shielding plate **401** is placed at a fixed position with respect to

the cold cathode **101** and the storage film **105** is moved, the configuration of the movable part is easily simplified because the storage film **105** is located at the outside of the shielding plate **401**. Alternatively, since the relative positions of the cold cathode **101** and the shielding plate **401** do not change, the cold cathode **101** and the shielding plate **401** may be united so as to simplify the configuration and fabricate the apparatus with ease. In addition, the cold cathode **101** only needs to emit electrons in such a manner as to allow only a portion associated with the hole **401a** in the shielding plate **401** to be irradiated with an electron beam E. Accordingly, power consumption is easily reduced.

In the case of using the shielding plate **401** as described above, a conductor **403** may be provided around the hole **401a** as shown in FIG. 16, for example, and a given voltage may be applied to the conductor **403** so that an electric field functioning as a lens is generated. Then, part of an electron beam in the vicinity of the hole **401a** converges to also strike the storage film **105**, so that the efficiency in utilizing an electron beam is enhanced and a region smaller than the hole **401a** can be irradiated with the electron beam. Instead of the conductor **403** described above, the shielding plate **401** itself may have conductivity.

(Information storage apparatus including a plurality of information storage cells)

An information storage apparatus including a plurality of information storage cells **100** as described above and capable of writing and reading information at the same time will be described.

FIG. 17 is a perspective view showing a configuration of an information storage apparatus. In this information storage apparatus, the information storage cells **100** as shown in FIG. 1 are arranged in columns and rows. More specifically, the information storage apparatus includes a substrate **121** in which a plurality of holes **121a** are formed and cold cathodes **101** similar to the cold cathode shown in FIG. 1 and other components

are provided in the respective holes 121a. A storage film 105 is provided above the substrate 121 such that a vacuum is created between the substrate 121 and the storage film 105. (The substrate 121 and the storage film 105 may be closely in contact with each other so that the holes 121a are individually kept under vacuum.)

5 Each four information storage cells 100 are determined as a group and four bits of data is written and read out as one word at the same time. Specifically, as shown in FIG. 18, for example, each four information storage cells 100 (e.g., S00 through S03) are set as a group and constitute a cell group 501 and a plurality of (e.g., four in the example shown in the drawing) such cell groups 501 are provided.

10 Cathode line drivers 111 are associated with the respective cell groups 501. One of the cathode ray drivers 111 is selected by an address decoder 502 for decoding two highest-order bits of a word address and a negative voltage (e.g., -5V) is applied to the cold cathodes 101 of the information storage cells 100 constituting the associated cell group 501.

15 A deflection controlling circuit 114 is common to the information storage cells 100 in all the cell groups 501, generates a deflecting voltage according to, for example, 14 lowest-order bits of the word address and applies the voltage to deflection electrodes 104 in the respective information storage cells 100. (In a case where recording points are arranged on the storage film 105 two-dimensionally, it is sufficient that the above-mentioned lowest-order bits are further divided and two deflecting voltages associated with
20 the divided bits are generated.)

One acceleration controlling circuit 112 and one signal regenerator 115 are common to the information storage cells 100 at the same bit position in the respective cell groups 501.

25 In the information storage apparatus, to store data, a negative voltage is applied to

the cold cathodes **101** of the information storage cells **100** in one of the cell groups **501** in accordance with the two highest-order bits of a word address. The acceleration controlling circuits **112** apply voltages according to written data to the accelerating electrodes **102** in the respective information storage cells **100**. Accordingly, in a part of the storage film **105** associated with the information storage cells **100** whose cold cathodes **101** have received the negative voltages, a region associated with 14 lowest-order bits of a word address is irradiated with electron beams at energy levels according to respective bits of the written data. Then, as already described with reference to FIG. 1, a phase change film **105a** is changed into an amorphous state or a crystallized state, thereby storing the written data accordingly.

On the other hand, to read stored data, the cathode ray drivers **111** apply negative voltages to the cold cathodes **101** of the information storage cells **100** in some of the cell groups **501** associated with the two highest-order bits of the word address. At the same time, the acceleration controlling circuits **112** apply given voltages to the accelerating electrodes **102** in accordance with a read control signal. Then, an associated part of the storage film **105** is irradiated with an electron beam at an energy level lower than that in writing, so that the voltages at the detection electrodes **105b** are detected by the signal regenerators **115**, thereby reading stored data.

As described above, writing or reading is performed at the same time on a plurality of (e.g., four) information storage cells **100** constituting each of the cell groups **501**, so that high-speed access is achieved. In addition, one of the cell groups **501** is selected in accordance with a part of the address, so that data corresponding to words in a number that is equal to the number obtained by (the number of recording points in the respective information storage cells **100**) \times (the number of cell groups **501**.) That is, if 4×4 information storage cells **100** each capable of storing $128 \times 128 = 16$ Kbits of data are

provided as shown in FIG. 18, an information storage apparatus capable of storing 64 Kwords \times 4 bits of data is obtained. If 1024×1024 information storage cells **100** each capable of storing $128 \times 128 = 16$ Kbits of data are provided on a 1 μ m-square recording plane, for example, a 1 mm-square storage film **105** is capable of storing a large amount of
 5 16 Gbits (about 10 Tbits/square inches) of data at a high density.

In the foregoing example, each cell group **501** is constituted by four information storage cells **100** arranged in a line (i.e., data is written in and read out from these cells at the same time.) Alternatively, each cell group **501** may be constituted by information storage cells **100** arranged in a plurality of lines. In this case, as long as the acceleration
 10 controlling circuit **112** and the signal regenerator **115** associated with each information storage cell **100** are provided, data may be written in and read out from all the information storage cells **100** at the same time.

In the foregoing example, voltages to be applied to the cold cathodes **101** are controlled in accordance with addresses whereas voltages to be applied to the accelerating
 15 electrodes **102** are controlled in accordance with written data. Alternatively, these voltages may be controlled conversely. Alternatively, only voltages to be applied to the cold cathodes **101** or the accelerating electrodes **102** may be controlled based on addresses and written data, for example.

As described with reference to FIG. 15, in a case where a region to be irradiated
 20 with an electron beam by moving at least one of the shielding plate **401** having a minute hole **401a** and the storage film **105** by the actuator **402**, shielding plates **401** and/or storage films **105** of a plurality of information storage cells **100** may be moved by the same actuator **402** or these components may be moved by actuators **402** using a common control signal. Alternatively, the shielding plates **401** and/or the storage film **105** for the plurality
 25 of information storage cells **100** may be united.

(Servo control of electron-beam irradiated position)

An example of an information storage apparatus in which an electron beam is controlled to be accurately applied to a region of the storage film **105** associated with a storage bit will be described.

5 In addition to one or a plurality of information storage cells **100** as shown in FIG. 1, this information storage apparatus includes a servo cell **600** as shown in FIG. 19. This servo cell **600** has a configuration similar to that of the information storage cells **100** but includes an insulating film **611** and an anode **612** instead of the storage film **105**. The insulating film **611** has minute holes **611a** formed in positions associated with respective
10 storage bits. The anode **612** is connected to an applied-current detector **621** so that the amount of current caused to flow by an electron beam incident via the minute holes **611a** formed in the insulating film **611** is detected. The result of the detection by the applied-current detector **621** is input to a control amount adjusting circuit **622**. Given control signals are input from the control amount adjusting circuit **622** to an acceleration
15 controlling circuit **112**, a convergence controlling circuit **113** and a deflection controlling circuit **114**. These control signals are also input to the acceleration controlling circuits **112**, the convergence controlling circuits **113** and the deflection controlling circuits **114** in the information storage cells **100**.

 In the information storage apparatus with the foregoing configuration, calibration is
20 performed on the amount of deflection and the state of convergence of an electron beam before data is stored or read out. Specifically, current distribution by the electron beam exhibits normal distribution having the maximum value at its center, for example. Accordingly, with respect to current flowing in the anode **612** by an electron beam incident on the anode **612** via each of the minute holes **611a**, the center of the electron beam
25 coincides with the center of the minute hole **611a** and the current is at the maximum when

the beam diameter of the electron beam at the insulating film 611 is at the minimum. In view of this, the amount of deflection and the degree of convergence are varied to small extent at every minute hole 611a so that an optimum value of the control amount at which the current flowing in the anode 612 is at the maximum is obtained and held in the control amount adjusting circuit 622. Based on this optimum value, the control amount adjusting circuit 622 outputs convergence control signals and deflection control signals to the information storage cells 100 in storing and reading data. This ensures stable operation in which variation in configuration occurring in fabrication and variation in deflection amount due to variations of power supply voltage and temperature and others are corrected.

More specifically, the calibration is performed by, for example, control operation of the control amount adjusting circuit 622 in the following manner.

(1) First, the amount of deflection is adjusted to zero by setting a voltage applied to the deflection electrode 104 at zero. An electron beam is generated so as to almost pass through a minute hole 611a formed at (near) the center of the insulating film 611. Under this condition, a voltage applied to the convergence electrode 103 is changed so as to maximize current flowing in the anode 612, i.e., to cause the electron beam to converge near the insulating film 611, so that current density is enhanced.

(2) Next, the voltage applied to the deflection electrode 104 is slightly varied such that the current flowing in the anode 612 is maximized, i.e., the minute hole 611a is accurately irradiated with the electron beam. (In a case where recording points are two-dimensionally arranged, it is sufficient to deflect the electron beam to small extent in the X and Y directions alternately so as to maximize the current.)

(3) Then, the degree of convergence of the electron beam is adjusted in the same manner as in (1).

Through (1) through (3), the position irradiated with the electron beam and the focal point of convergence are coincide with each other with respect to the minute hole **611a** located at the center of the insulating film **611**.

(4) The amount of deflection is varied stepwise to a sufficiently small amount at each step from the minimum to the maximum so that the electron beam is gradually moved from an edge of a storage region to the other in the storage film **105**. In this way, a control amount at which the current flowing in the anode **612** is at the maximum is obtained and is held in the control amount adjusting circuit **622**. That is, a deflection amount at which current flowing upon irradiation with an electron beam via each minute hole **611a** formed through the insulating film **611** is at the maximum is obtained and held. A voltage applied to the convergence electrode **103** for each minute hole **611a** may also be controlled. In addition, voltages applied to the cold cathode **101** and the accelerating electrode **102** may also be controlled so as to reduce variation in the intensity of an electron beam.

In storing and reading data, control signals are input from the control amount adjusting circuit **622** to the respective information storage cells **100** based on the control amount held in the foregoing manner, so that high reproducibilities of the irradiated position and the degree of convergence of an electron beam are obtained and data is stored and read out with accuracy. Accordingly, the storage density is further increased and, in addition, the efficiency in utilizing an electron beam is easily enhanced.

In the foregoing example, the insulating film **611** having the minute holes **611a** is used. However, the present invention is not limited to this. A resistor or the like may be placed on, for example, the anode **612** so as to detect current varying depending on the presence and absence of the resistor or the like at the position irradiated with an electron beam. Alternatively, a resistive film or a resistive plate having a uniform resistivity may be provided and a position irradiated with an electron beam may be detected based on

voltages near the midpoints of the respective four sides or vertexes, for example, so as to irradiate a given position with an electron beam. In the case of ensuring the accuracy in irradiating a relative position with an electron beam with respect to each recording point, calibration as described above may be performed only on one of the recording points so that the amounts of deflection with respect to the other recording points are controlled based on the calibration.

Only one servo cell **600** as described above may be provided in the entire information storage apparatus. In a case where a large number of the information storage cells **100** are provided, for example, the servo cell **600** may be provided for each given number of information storage cells **100**.

The calibration is not necessarily performed before data is stored or read out in the manner as described above. Alternatively, feedback control may be performed on a position irradiated with an electron beam in the servo cell **600** with emission of electron beams in the information storage cells **100** suppressed, and then emission of the electron beams in the information storage cells **100** may start when the irradiated position in the servo cell **600** comes to a target position. In addition, a conductor or a slit may be provided at a reference position in the insulating film **611** in the servo cell **600** or in the periphery of the storage film **105** in the information storage cells **100** so as to perform writing or reading in accordance with a timing from the point of time when the conductor, for example, is irradiated with an electron beam during scanning with the electron beam.

In a case where a phase change film or the like is used as a storage medium as in the foregoing example, a nonvolatile information storage apparatus is obtained. However, the storage medium is not limited to this and various components may be used.

Specifically, an insulator film, for example, may be used to utilize the presence and absence of accumulated charge due to electron avalanche as described in the description of

the conventional technique. Alternatively, to store data, charge may be accumulated by injecting electrons into a high-resistance film at low speed or electrons may be implanted at high speed so that the accumulated charge is expelled by electron avalanche. On the other hand, to read stored data, the presence or absence of electron avalanche according to a charged state before irradiation with an electron beam may be detected depending on the amount of current. A component which changes its shape, e.g., comes to have a hall therein or has its thickness reduced by thermal deformation, upon irradiation with a high-energy electron beam and causes current flowing in an electrode at the backside to vary upon irradiation with a low-energy electron beam, such as a thin film made of a metal having a low melting point, may be used. In this case, a component made of a conductive material having a high resistivity, for example, is preferably used so as to make current quickly escape when a portion having its thickness unchanged and other portions is irradiated with an electron beam. Alternatively, a component such as a photonic material which comes to have a fluorescent property by irradiation with a high-energy electron beam may be used so as to detect fluorescence occurring upon irradiation with a low-energy electron beam by using an optical sensor.

The energy of an electron beam is not necessarily controlled by using voltages applied to the cold cathode **101** and the accelerating electrode **102** and may be controlled by changing the duty ratio between pulses applied thereto and the number of such pulses or the diameter of a beam spot through adjustment of the degree of convergence, for example.

In a case where a plurality of information storage cells **100** are provided, part of the cells may be used to store error detecting and correcting code. Specifically, as shown in FIG. **20**, for example, out of 1024 bits to be written and read out as, for example, one word at the same time from a cell group **701** including 1024 information storage cells **100**, 64 bits may be used as parity bits (error detecting and correcting code) for the other 960 bits

so that error detection and error correction are performed by a cyclic redundancy check (CRC) or other operations.

INDUSTRIAL APPLICABILITY

5 As described above, according to the present invention, a minute region of a storage medium is irradiated with an electron beam emitted from a cold cathode so that information is stored and read out. Accordingly, an area necessary for storing one bit is greatly reduced and a large amount of information is stored at a high density. In addition, the apparatus size and power consumption are easily reduced and high-speed access is
10 achieved. A plurality of bits of information is written and read out in parallel so that the speed is further increased. In addition, the position irradiated with an electron beam is subjected to servo control, so that influences of variations in power supply voltage, temperature and fabrication are reduced and high reliability is obtained. As a result, irradiation of the storage medium with an electron beam is effective for information
15 storage apparatuses and others that store and read information.